MICROWAVE EMISSION FROM POLAR SURFACES

Thomas C. Grenfell
Department of Atmospheric Sciences
University of Washington
Seattle, Washington 98195-1640
phone: (206) 543-9411, fax: (206)543-0308, e-mail: tcg@atmos.washington.edu
Award #: N00014-89-J-1140

LONG-TERM GOAL

Our long-term goals for this project have been to understand the relationships between microwave emission signatures from centimeter to millimeter wavelengths and the physical, structural, and optical properties of arctic and Antarctic sea ice. This has provided fundamental information for determining how effectively multifrequency multipolarization passive microwave satellite data can be used to identify the spatial and temporal distribution of the different types, ages and surface temperatures of sea ice. In the last five years we have concentrated on determining and understanding the microwave signatures of new and young ice from initial formation through to the development of thick first-year ice. Ice types in this range are difficult to resolve from space but play a major role in the transfer of energy between the polar oceans and the atmosphere. At the same time we have broadened our scope to include a comparison of the passive microwave signatures with radar, visible, and infrared in order to be able to combine the information from a wide variety of satellite sensors in a consistent fashion.

SCIENTIFIC OBJECTIVES

Because of the importance of new and young ice types for the regional energy balance and dynamical behavior of the ice covered oceans, our principal objective has been to investigate the temporal dependence of combined electromagnetic signatures of sea ice types from open water and new ice through thick first-year ice to relate this dependence to changes in the physical properties of the ice via direct theoretical modeling. We have been concentrating in particular on the growth of thin congelation and frazil/pancake ice, with special emphasis on the transition from young ice to first-year ice. Other cases of direct interest in which we have participated include investigations of (1) the influence of a snow cover on thin ice, (2) bare versus snow-covered thick first-year ice, (3) the contrast between the signatures of congelation and frazil/pancake ice, and (4) the effects of deformed or ridged ice. Because we now have available detailed observations of the physical properties of the ice for these cases, it is now practical to include these results in suitable direct theoretical models to predict electromagnetic signatures. Our goal in this respect has been to use our models with consistent sets of input data to compare predicted and observed electromagnetic signatures.

APPROACH

Our approach has been to compile the passive microwave and thermal infrared observations of sea ice from all of our recent field experiments in order to refine our estimates of the signature evolution in selected two dimensional parameter spaces: for example e[18.7GHz,V-Pol] versus

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1997**	2. REPORT TYPE	3. DATES COVERED **00-00-1997 to 00-00-1997**
4. TITLE AND SUBTITLE **Microwave Emission from Polar Surfaces**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Washington,Department of Atmospheric Sciences,Seattle,WA,98195**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S)
		11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

e[37GHz,V-Pol]) and PR versus GR (see Figure 1). This year we have incorporated into the comparison active microwave, visible/near-infrared observations, physical and biological observations obtained concurrently at the CRREL pond and at Pt. Barrow.

Our core data set consists of surface- based measurements of brightness temperature (T_B) and emissivity at microwave frequencies of 6.7, 10, 18.7, 37, 90 GHz for vertical and horizontal polarization (V-Pol & H-Pol) and in the thermal infrared (8-14μm band - unpolarized). Angular scans are available at selected sites from 30-70^o nadir angle, and spatial scans at 50º nadir angle are available at 1 to 2 meter resolution. The radar data consist of C, X, and Ka-Band radar data obtained by S. Nghiem and R. G. Onstott. Optical data are spectral albedos from 400 to 1000 nm obtained by D. K. Perovich. Ice sheet characterization data consist of bulk properties - salinity, density, and temperature depth profiles - and microscopic scale properties related to the size distributions and correlation functions for brine pockets and vapor bubbles. These data were provided by D. K. Perovich and A. J. Gow. Particular and dissolved matter concentrations have been provided by C. Roesler.

During the last 4 years we have investigated the growth phases of congelation and pancake ice, the transition from new to young to first-year (FY) ice. We have concentrated on the relative importance of the near surface layers for both smooth ice and ice with a rough surface and/or a snow cover.

The first of the models we have used is a multilayer strong fluctuation theory (SFT) code based on the formulation of Stogryn for microwave emissivity and volume scattering. Our other model is a multilayer discrete ordinates radiative transfer model which is applicable in the ultraviolet, visible, and thermal infrared.

WORK COMPLETED

We have archived and carried out detailed analyses of the results primarily from seven field experiments (CEAREX 88-89, LEADEX 1992; CRREL 1993, 1994, & 1995; Beaufort & Chukchi Seas 1994; SIMMS 1995) that covers essentially all stages in the development of new, young, and first-year sea ice. We have made significant contributions to the production of eight scientific papers (listed below) involving various research themes of the electromagnetics ARI including a detailed study of the temporal evolution of electromagnetic signatures from initial formation through FY ice. We have cooperated with all the participants to exchange the data needed to build up the individual multisensor data sets. We have also successfully compared our model results with selected test cases and identified several important structural features of the ice.

RESULTS

A variety of comparative results have been obtained among the electromagnetic signatures of new and young ice. Shown in Figures 1 and 2 are scatter plots showing the correlations of spectral albedo at 500 nm with selected emissivities from 1.4 to 90 GHz, backscattering coefficients from C- to Ka-band, α_λ at 400 nm, and thermal infrared (IR) emissivity. Almost all these quantities increase initially with increasing albedo as the thin ice develops, but the higher frequency microwave emissivities decrease with further albedo increases which arise from the addition of a snow layer. Values of σ^o level off for thicker ice although the introduction of snow increases the backscatter by several dB. The initial positive correlation is due to increases in bulk dielectric properties and the establishment of surface roughness. The negative correlation for millimeter wave emissivities is due to increased volume scattering in the snow as seen in σ^o.

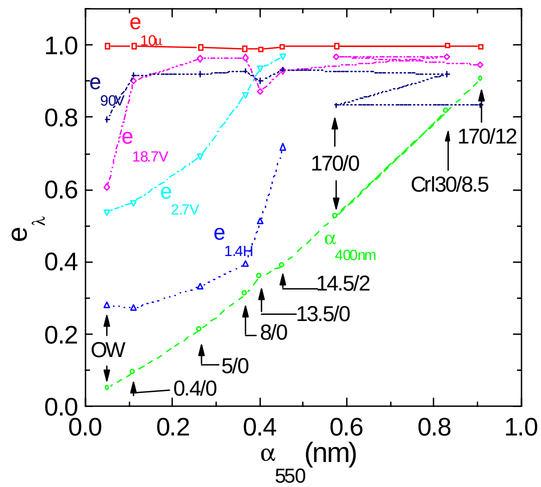

Figure 1. Comparison of Spectral Albedo at 550 nm with Selected Microwave and Thermal IR Emissivities, e_{fp} (f-frequency and p-polarization) and with α_λ at 400 nm for Selected Ice and Snow Thickness. The Numbers Associated with each Albedo Value Indicate the Ice Thickness/Snow Thickness (cm).

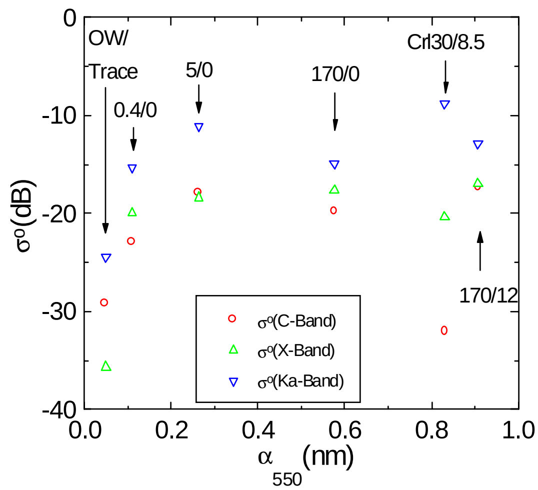

Figure 2. Comparison of Spectral Albedo at 550 nm with Microwave Backscattering Coefficients

for Selected Ice and Snow Thickness. The Ice Thickness/Snow Thickness in cm are Indicated as in Figure 1.

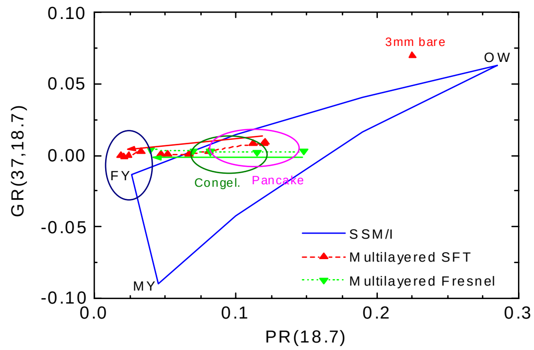

Figure 3. Theoretical Calculations of PR-GR Evolution from Young Ice to Thick First-Year Ice Using Mutilayer Strong Fluctuation Theory (SFT) and Fresnel Models.

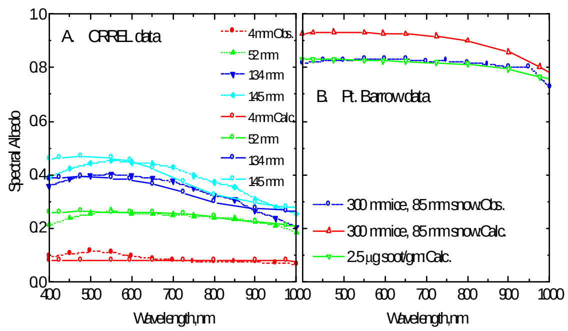

Figure 4. Comparison of Radiative Transfer model calculations(4-stream discrete-ordinates radiative transfer model)

The model includes spectral albedo observations versus ice and snow thickness: A. bare ice from 4 mm to 145 mm thickness; B. 300 mm thick ice with 85 mm snow and 85 mm of snow plus 2.5 mg soot/gm

Figures 3 and 4 show model results for microwave emissivity and spectral albedo for selected cases. In both cases we obtain a good match with the observations adhering to the constraints of the observations of the physical properties. Some refinements are indicated, however, such as the inclusion of surface roughness and absorption by chlorophyll. For modeling the signature evolution, we find that proper representation of vertical structure is crucial and that multilayer models are required (up to 17 layers were used here). In particular, the brine volume and bubble density profiles or grain size distribution must be represented accurately, so a single layer is not sufficient to represent either the ice or the snow.

IMPACT/APPLICATION

Based on the work described above, our observations and modeling work have revealed several considerations which are central to understanding the physical basis for the application and interpretation of thin ice algorithms for passive microwave imagery. Our results have shown that passive microwave measurements provide one of the most robust remote sensing techniques for distinguishing among sea ice types - including the energetically important thin ice types. We have found that current theories applicable at microwave frequencies (multilayer SFT wave theory, for example) and in the visible and infrared (radiative transfer theory) can reproduce the radiation signatures of FY ice types quite well by incorporating the actual physical structure of the ice. As a result of the cooperative work carried out during the electromagnetics ARI, the determination of the wavelength regions and physical situations appropriate for the application of various models has been improved considerably, and our results, both theoretical and observational, have demonstrate the levels of accuracy of the models. It is clear that our understanding of the microwave emissivities of sea ice and their relation to other types of remote sensing signatures has increased significantly in the course of the ARI. The primary remaining limitation on passive microwave remote sensing is the coarse spatial resolution of the satellite imagery, and it is our primary recommendation that presently-available aperture-synthesis techniques should be applied to building large satellite antennas to enhanced the spatial resolution.

TRANSITIONS

The techniques developed on this grant and the observational and modeling results from this project will be used in future research to determine the spatial and temporal distribution of the properties of sea ice. We plan to make direct use of these, for example, in the next two years as part of our involvement with SHEBA. We also anticipate that these results, currently submitted for publication, will have a significant impact on radar and visible/near-infrared remote sensing.

RELATED PROJECTS

We have been working on detailed comparisons of our passive microwave results with visible, infrared, and radar observations for several different categories of sea ice at different stages of evolution. This has involved data exchange, cooperative modeling, and collaboration in preparing the publications with all the research groups participating in the Electromagnetics ARI including the observers and the theoretical modelers.